

**BIG IMPACTS AND TRANSIENT OCEANS ON TITAN.** K. J. Zahnle<sup>1</sup> D. G. Korycansky<sup>2</sup> and C. A. Nixon<sup>3</sup>,  
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**Introduction:** We have studied the thermal consequences of very big impacts on Titan [1]. Titan's thick atmosphere and volatile-rich surface cause it to respond to big impacts in a somewhat Earth-like manner. Here we construct a simple globally-averaged model that tracks the flow of energy through the environment in the weeks, years, and millenia after a big comet strikes Titan. The model Titan is endowed with 1.4 bars of N<sub>2</sub> and 0.07 bars of CH<sub>4</sub>, methane lakes, a water ice crust, and enough methane underground to saturate the regolith to the surface.

We assume that half of the impact energy is immediately available to the atmosphere and surface while the other half is buried at the site of the crater and is unavailable on time scales of interest. The atmosphere and surface are treated as isothermal. We make the simplifying assumptions that the crust is everywhere as methane saturated as it was at the Huygens landing site, that the concentration of methane in the regolith is the same as it is at the surface, and that the crust is made of water ice. Heat flow into and out of the crust is approximated by step-functions. If the impact is great enough, ice melts. The meltwater oceans cool to the atmosphere conductively through an ice lid while at the base melting their way into the interior, driven down in part through Rayleigh-Taylor instabilities between the dense water and the warm ice. Topography, CO<sub>2</sub>, and hydrocarbons other than methane are ignored. Methane and ethane clathrate hydrates are discussed quantitatively but not fully incorporated into the model.

We find that a nominal Menrva impact would have been big enough to raise the surface temperature by ~80 K. Nominal Menrva would have doubled the methane inventory at the surface. The mobilized methane would have drizzled out of the atmosphere over hundreds of years, filling lake beds, oil pans, whatever. Uncertainties in the impact energy and the partitioning of the energy into the atmosphere correspond to a factor two uncertainty in the temperature rise. Menrva was probably not big enough to heat the 1.4 bar N<sub>2</sub> atmosphere to the melting point of water, but some global-distributed surface melting cannot be ruled out at the high end of the uncertainty.

Bigger impacts are more invigorating. If Titan's surface is mostly made of water ice, the putative Hotei impact (a possible 800-1200 km diameter basin, [1])

raises the average surface temperature to 350-400 K. Global meltwaters might range between 50 m to more than a kilometer deep, depending on the size of the event and how rapidly bedrock ice warms and founders. Water rain must fall, flow, and pool, subject to choking and crusting over with flotsam, the later including a variety of hydrocarbons, some of them liquid. Global meltwater oceans do not last more than a few decades or centuries at most, but are interesting to consider given Titan's organic wealth. When it finally fully freezes the ocean would be on the order of a kilometer deep.

Hotei scale events, regardless of whether Hotei is itself a real exemplar, must have played a role in the history of Titan, as it is not plausible to build a world as big as Titan and not have big impacts.

Clathrate hydrates might form under some of the conditions discussed here. Unfavorable kinetics would seem to restrict formation of the binary methane hydrate to depths greater than ~1 kilometer of ice. Nonetheless it appears likely that methane migrating from below could have been caught in clathrates between 1 and 2 km depth, with capacity to store one to two orders of magnitude more methane than is currently in the atmosphere.

Impacts also create local crater lakes but, in disagreement with previous studies, we conclude that the lakes are likely to be deeply buried and very short-lived. The problem is that liquid water is denser than ice. Crater lakes form in shock-heated warm ice of relatively low viscosity. Rayleigh-Taylor instabilities in the warm ice grow quickly, the lakes founder, and the water mixes with ice. Any liquid water that remains unfrozen sinks to the bottom of the crater where it either pools kilometers below the surface in contact with cold bedrock ice. These concerns are general for any large icy satellite and not particular to Titan.

#### References:

- [1] Zahnle K. J., Korycansky D. G., and Nixon D. G. (2013). *Icarus* (in press). [2] Soderblom L. A., Brown, R. H., Soderblom, J. M., Barnes, J. W., Kirk, R. L., Sotin, C., Jaumann, R., Mackinnon, D. J., Mackowski, D. W., Baines, K. H., Buratti, B. J., Clark, R. N., and Nicholson, P. D. (2009). *Icarus* 204, 610–618.